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BROOKHAVEN
NATIONAL LABORATORY

Managed by Brookhaven Science Associates
for the U.S. Department of Energy

Memo

Date: *June 1, 2005*

To: *Ed Lessard*

From: *Benny Hooda*

Subject: *NESHAPs Review of the Laser Electron Stripping Experiment*

As per your request, a NESHAPs compliance review of the laser electron stripping experiment and the pertinent source term information provided in the paper titled, "Airborne Radioactivity at 200 MeV Laser Stripping Experiment in Building 937" was completed.

The laser electron stripping experiment would be performed in the tunnel of Radiation Effects Facility (REF), building 937. The source term was based on the production rate of 0.2 thermal and fast neutrons per proton. The proton energy was at 200 MeV and had a beam intensity of 1.85E10 protons. The REF tunnel is equipped with a 255 cfm fan that vents to the outside via a 6-inch inner diameter, and 2-meter high stack. A HEPA filtration system will be used to prevent the release of any particulate radioactivity to the environment. The laser electron stripping experiment is scheduled for three weeks and will operate for 20 hours per week. The principal radionuclides that could be of any significance from an environmental risk and dose compliance perspective are ^{11}C ($T_{1/2}$ = 20 min., β^+), ^{13}N ($T_{1/2}$ = 10 min., β^+) and ^{15}O ($T_{1/2}$ = 2 min., β^+), ^{18}F ($T_{1/2}$ = 110 min., β^+), and ^{41}Ar ($T_{1/2}$ = 1.8 hr). A conservative estimate of the potential source term is given in Table 1.

The REF facility would be in compliance with the NESHAPs regulations for emissions during the laser stripping experiment. The effective dose equivalent to the MEI from the laser experiment was estimated to be 3.24E-07 mrem in a year at the southeast location. The potential dose was well below the 10 mrem/year annual NESHAPs limit as specified in the 40 CFR 61, subpart H, and below the 0.1mrem/ yr. limit, which requires a permit.

If you have any questions please call me at extension 8107.

BH: car

Attachments: Source Term Calculations
CAP88-PC dose estimates
Ed Lessard's paper

Distribution: J. Alessi G. Goode R. Karol R. Lee Y. Makdisi
M. Van Essendelft

File: EC72ER.05

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Table 1. Source Term for NESHAPs Evaluation

Target	# of target atoms (atom/sq.cm)	Neutron Flux (n/sec)	Cross Section (Sq. cm)	Nuclide	Half-life (minute)	Lambda (per minute	Release Rate (per minute)	Saturation Activity (atoms/sec)	Activity with ventilation and decay (Bq)	Activity with ventilation and decay (Curies)	Activity without HEPA (uCi/sec)*	Activity with HEPA (uCi/sec)*	Activity with HEPA (Curies)*	Activity with HEPA (Curies) Released*
N-14	6.63E+22	7.40E+09	3.00E-26	^{3}H	6.46E+06	1.07E-07	1.62E-02	1.47E+07	9.75E+01	2.64E-09	3.56E-07		7.69E-08	7.89E-08
O-16	1.70E+22	7.40E+09	3.00E-26								9.11E-08		1.97E-08	
N	6.63E+22	7.40E+09	1.00E-26	^{7}Be	7.63E+04	9.08E-06	1.62E-02	4.91E+06	2.75E+03	7.44E-08	1.00E-05		2.16E-06	
O	1.70E+22	7.40E+09	5.00E-27								1.28E-06		2.76E-07	
Ar-40	2.46E+20	7.40E+09	6.00E-28								2.23E-09		4.82E-10	2.46E-06
N-15	3.40E+19	7.40E+09	1.00E-26	^{11}C	2.04E+01	3.40E-02	5.02E-02	2.51E+03	1.70E+03	4.60E-08	1.22E-02	1.22E-02	2.64E-03	
O-18	1.98E+20	7.40E+09	7.00E-28								2.18E-04	2.18E-04	4.71E-05	
Ar	2.46E+20	7.40E+09	7.00E-28								3.16E-06	3.16E-06	6.83E-07	2.68E-03
N	6.63E+22	7.40E+09	1.64E-24	^{14}C	3.01E+09	2.30E-10	1.62E-02	8.05E+08	1.14E+01	3.09E-10	4.17E-08	4.17E-08	9.01E-09	9.01E-09
N	6.63E+22	7.40E+09	1.00E-26	^{13}N	9.96E+00	6.96E-02	8.58E-02	4.91E+06	3.98E+06	1.08E-04	1.46E-02	1.46E-02	3.15E-03	
O	3.40E+19	7.40E+09	9.00E-27								3.35E-03	3.35E-03	7.24E-04	
Ar	2.46E+20	7.40E+09	8.00E-28								4.32E-06	4.32E-06	9.33E-07	3.88E-03
O	3.40E+19	7.40E+09	1.00E-27	^{14}O**	1.20E+00	5.78E-01	5.94E-01	2.51E+02	2.44E+02	6.61E-09	4.47E-04	4.47E-04	9.66E-05	
Ar	2.46E+20	7.40E+09	6.00E-29								3.89E-07	3.89E-07	8.40E-08	**
O	1.70E+22	7.40E+09	4.00E-26	^{15}O	2.03E+00	3.41E-01	3.58E-01	5.03E+06	4.80E+06	1.30E-04	1.76E-02	1.76E-02	3.80E-03	3.80E-03
Ar	2.46E+20	7.40E+09	6.00E-27	^{18}F	1.10E+02	6.30E-03	2.25E-02	1.09E+04	3.06E+03	8.27E-08	1.12E-05	1.12E-05	2.42E-06	2.42E-06
Ar	2.46E+20	7.40E+09	1.20E-28	^{24}Ne**	3.40E+00	2.04E-01	2.20E-01	2.19E+02	2.02E+02	5.47E-09	7.41E-07	7.41E-07	1.60E-07	**
Ar	2.46E+20	7.40E+09	1.00E-26	^{22}Na	1.37E+06	5.06E-07	1.62E-02	1.82E+04	5.69E-01	1.54E-11	2.08E-09		4.49E-10	4.49E-10
Ar	2.46E+20	7.40E+09	7.00E-27	^{24}Na	9.00E+02	7.70E-04	1.70E-02	1.28E+04	5.79E+02	1.56E-08	2.11E-06		4.56E-07	4.56E-07
Ar	2.46E+20	7.40E+09	2.50E-27	^{27}Mg**	9.46E+00	7.33E-02	8.95E-02	4.55E+03	3.73E+03	1.01E-07	1.36E-05		2.94E-06	**
Ar	2.46E+20	7.40E+09	4.00E-28	^{28}Mg**	1.25E+03	5.54E-04	1.68E-02	7.29E+02	2.41E+01	6.52E-10	8.77E-08		1.89E-08	**
Ar	2.46E+20	7.40E+09	1.30E-26	^{28}Al**	2.25E+00	3.08E-01	3.24E-01	2.37E+04	2.25E+04	6.08E-07	8.23E-05		1.78E-05	**
Ar	2.46E+20	7.40E+09	4.00E-27	^{29}Al**	6.60E+00	1.05E-01	1.21E-01	7.29E+03	6.31E+03	1.71E-07	2.31E-05		4.99E-06	**
Ar	2.46E+20	7.40E+09	6.00E-27	^{31}Si**	1.57E+02	4.41E-03	2.06E-02	1.09E+04	2.34E+03	6.33E-08	8.54E-06		1.84E-06	**
Ar	2.46E+20	7.40E+09	4.40E-27	^{30}P**	2.50E+00	2.77E-01	2.93E-01	6.02E+03	7.57E+03	2.05E-07	2.77E-05		5.98E-06	**
Ar	2.46E+20	7.40E+09	2.50E-26	^{32}P	2.06E+04	3.36E-05	1.62E-02	4.55E+04	9.44E+01	2.55E-09	3.44E-07		7.43E-08	7.43E-08
Ar	2.46E+20	7.40E+09	9.00E-27	^{33}P**	3.64E+04	1.90E-05	1.62E-02	1.64E+04	1.92E+01	5.20E-10	7.02E-08		1.52E-08	**
Ar	2.46E+20	7.40E+09	2.30E-26	^{35}S**	1.26E+05	5.50E-06	1.62E-02	4.19E+04	1.42E+01	3.84E-10	5.19E-08		1.12E-08	**
Ar	2.46E+20	7.40E+09	7.00E-28	^{34m}Cl**	3.20E+01	2.17E-02	3.79E-02	1.28E+03	7.29E+02	1.97E-08	2.67E-06	2.67E-06	5.77E-07	**
Ar	2.46E+20	7.40E+09	6.6E-25	^{41}Ar	1.08E+02	6.42E-03	2.26E-02	1.20E+06	3.41E+05	9.22E-06	1.25E-03	1.25E-03	2.70E-04	2.70E-04

* Calculated Release Activity from Lessard's Paper.
** Not in the CAP88 Library

CAP88-PC

Version 2.10

Clean Air Act Assessment Package - 1988

SYNOPSIS REPORT

Non-Radon Population Assessment
May 31, 2005 10:12 am

Facility: Building 937(REF) Laser Stripping Experiment
Address: Brookhaven National Laboratory
P.O.Box 5000
City: Upton
State: NY Zip: 11973

Source Category: Small Stack
Source Type: Stack
Emission Year: 2005

Comments: Dose Calculation from Air Activation

Effective Dose Equivalent
(mrem/year)

3.24E-07

At This Location: 2500 Meters Southeast

Dataset Name: Bldg. 937
Dataset Date: 5/31/2005 10:12:00 AM
Wind File: Z:\CAP88PC2\CAP88PC2\WNDFILES\BNL00.WND
Population File: Z:\CAP88PC2\CAP88PC2\POPFILES\BNL98A.POP

MAXIMALLY EXPOSED INDIVIDUAL

Location Of The Individual: 2500 Meters Southeast
Lifetime Fatal Cancer Risk: 7.95E-12

ORGAN DOSE EQUIVALENT SUMMARY

Organ	Selected Individual (mrem/y)	Collective Population (person-rem/y)
GONADS	3.70E-07	1.99E-06
BREAST	3.43E-07	1.83E-06
R MAR	2.84E-07	1.54E-06
LUNGS	3.44E-07	1.79E-06
THYROID	3.46E-07	1.87E-06
ENDOST	3.21E-07	1.70E-06
RMNDR	2.83E-07	1.53E-06
EFFEC	3.24E-07	1.74E-06

FREQUENCY DISTRIBUTION OF LIFETIME FATAL CANCER RISKS

Risk Range	# of People	# of People in This Risk Range or Higher	Deaths/Year in This Risk Range	Deaths/Year in This Risk Range or Higher
1.0E+00 TO 1.0E-01	0	0	0.00E+00	0.00E+00
1.0E-01 TO 1.0E-02	0	0	0.00E+00	0.00E+00
1.0E-02 TO 1.0E-03	0	0	0.00E+00	0.00E+00
1.0E-03 TO 1.0E-04	0	0	0.00E+00	0.00E+00
1.0E-04 TO 1.0E-05	0	0	0.00E+00	0.00E+00
1.0E-05 TO 1.0E-06	0	0	0.00E+00	0.00E+00
LESS THAN 1.0E-06	5053193	5053193	6.05E-10	6.05E-10

RADIONUCLIDE EMISSIONS DURING THE YEAR 2005

Nuclide	Class	Size	Source #1 Ci/y	TOTAL Ci/y
H-3	*	0.00	7.7E-08	7.7E-08
C-11	D	1.00	2.7E-03	2.7E-03
C-14	*	0.00	9.0E-09	9.0E-09
N-13	D	1.00	3.9E-03	3.9E-03
O-15	D	1.00	3.8E-03	3.8E-03
F-18	Y	1.00	2.4E-06	2.4E-06
NA-22	D	1.00	4.5E-10	4.5E-10
NA-24	D	1.00	4.6E-07	4.6E-07
P-32	W	1.00	7.4E-08	7.4E-08
AR-41	*	0.00	2.7E-04	2.7E-04
BE-7	Y	1.00	2.5E-06	2.5E-06

SITE INFORMATION

Temperature: 10 degrees C
Precipitation: 121 cm/y
Humidity: 8 g/cu m
Mixing Height: 1000 m

SOURCE INFORMATION

Source Number: 1

Stack Height (m): 2.00
Diameter (m): 0.15

Plume Rise
Momentum (m/s): 6.58
(Exit Velocity)

AGRICULTURAL DATA

	Vegetable	Milk	Meat
Fraction Home Produced:	0.000	0.000	0.000
Fraction From Assessment Area:	0.000	0.000	0.000
Fraction Imported:	1.000	1.000	1.000

Beef Cattle Density: 5.83E-02
Milk Cattle Density: 8.56E-02
Land Fraction Cultivated
for Vegetable Crops: 1.88E-02

POPULATION DATA

Direction	Distance (m) 500	1375	2000	2500	3000	9625	24000
N	0	0	0	0	1	4650	0
NNW	0	0	0	0	1	7845	0
NW	0	0	0	0	1	18410	1605
WNW	0	0	0	0	1	42735	59885
W	0	0	0	0	1	50715	137075
WSW	0	0	97	0	1	38830	147520
SW	0	0	198	0	1	22325	66440
SSW	0	0	0	0	1	21875	1120
S	0	0	0	0	1	15900	35
SSE	0	0	0	0	1	22925	0
SE	0	0	0	1	1	9270	16325
ESE	0	0	0	0	1	6375	7080
E	0	0	0	0	1	3095	765
ENE	0	0	0	0	1	2540	0
NE	0	0	0	1	1	3015	0
NNE	0	0	0	0	1	7740	0

Direction	Distance (m) 40000	56000	72000
N	94925	252075	262180
NNW	211745	108585	54880
NW	137435	124535	104675
WNW	135	217780	131090
W	243225	227190	373120
WSW	360480	427075	778140
SW	3495	0	0
SSW	0	0	0
S	0	0	0
SSE	0	0	0
SE	0	0	0
ESE	0	0	0
E	17765	9250	585
ENE	13175	15220	2300
NE	0	13750	33525
NNE	7125	45010	66315

Airborne Radioactivity at 200 MeV Laser Stripping Experiment, Building 937 (REF)

E. Lessard

Radioactivity Production and Release

The principal source of radioactivity in air at accelerators is due to the interaction of primary and secondary particles directly with the air in the experimental enclosure.

Table 1 gives the abundances and number densities of atoms of the most common stable isotopes found in the atmosphere by volume percentage and in terms of the atom density, A_j. The atom density is used with the travel path of neutrons to estimate the number of target atoms seen by secondary radiation traveling through the air in the tunnel. The tunnel is 3.33 m diameter by 67 m long. The mean path traveled in air by a secondary hadron is estimated to be 15.8 m. The atom-density thickness, N_j, for the REF tunnel is the product of the atom density and the mean travel path in air for secondary radiation. The atom-density thickness was averaged over the relevant spatial volume of the REF tunnel.

Table 1 Stable target atom percentage by volume in the atmosphere and atom density, A_j, at room temperature (Co04)

Isotope	Percentage by volume in the atmosphere	Aj (atoms cm^{-3}) at room temperature
^{14}N	78.16	4.199×10^{19}
^{16}O	20.00	1.075×10^{19}
^{40}Ar	0.467	1.558×10^{17}
^{15}N	0.290	2.149×10^{16}
^{18}O	0.040	1.255×10^{17}

The general activation equation (Co04), to derive the total specific activity, *S* (typically in units of Bq cm^{-3}) of an enclosed volume of radioactive air is:

$$S = C\sum_i \left\{ \sum_j N_j \sigma_{ij_\gamma} \phi_\gamma + \sum_j N_j \sigma_{ij_{th}} \phi_{th} + \sum_j N_j \sigma_{ij_{HE}} \phi_{HE} \right\} \{1 - \exp(-\lambda_i t_i)\} \exp(-\lambda_i t_c)$$

In this case, ϕ_γ, ϕ_{th}, and ϕ_{HE}, represent the average photon, thermal neutron, and high energy particle currents (particles per second) leaving the graphite collimator and stop, respectively. In this equation t_i is the irradiation time while t_c represents the decay time. The σ_{ij} values are the corresponding cross sections, which are energy dependant. The constant, *C*, is the conversion to specific activity and is equal to unity for activity in Becquerels cm^{-3} if all the units of length implicit in the quantities in the equation are expressed in cm. The outer sum over index *i* includes all possible radionuclides produced and the sum over the index *j* sums over the parent-target atoms found in air.

Table 2 lists the radionuclides that can be produced from the principle constituents in air and an estimate of the average production cross section. The large cross sections for (n, γ) and (n, p) reactions are for captures of neutrons of thermal energies ($E_n \approx 0.025$ eV) while the remaining cross sections are generally the saturation cross sections found in the region above approximately a few 10's of MeV. Gamma-induced reactions are present at virtually all accelerators and at most energies; however, they are much more significant for electron accelerators since radiative energy losses are inversely proportional to the mass of the accelerated particle. Thus, γ-induced reactions are not considered here for protons at 200 MeV.

The beam intensity requested by the experiment is 1.85×10^{10} protons per second, and the experimenters plan to use the beam 4 hours per day, 20 hours per week for three weeks. The proton beam will be stopped on thick graphite stops and collimators, at least 17.5 cm in length. Based on data in Tesch (Te85), there are 0.2 secondary high energy neutrons for each stopped 200 MeV proton. From Gabriel (Ga70), the secondary thermal neutron (< 0.5 eV) intensity is approximately equal to the intensity above 0.5 eV, thus, the number of thermal neutrons per proton was assumed to be 0.2.

It is assumed that all secondary radiation will traverse air in the tunnel and not be absorbed in the graphite stop or in surrounding shielding, shielding which is likely to be added in order to reduce the fault levels on the roadway above the stop. This assumption results in an overestimate of the airborne radioactivity in the tunnel.

Adjustments for the presence of ventilation during the run can be conveniently made for a given radionuclide by using an effective decay constant, λ' , that includes the physical decay constant, λ, along with a ventilation term, r,

$$\lambda' = \lambda + r ,$$

$$\text{where} \qquad r = \frac{D}{V} ,$$

with D being the ventilation rate in air volume per unit time and V being the enclosure volume (Co04). Thus r is the number of air changes per unit time. The specific activity in the tunnel, S, must also be multiplied by the fraction of activity leaving the tunnel by radioactive decay ($\lambda/\lambda+r$).

For the REF tunnel, a fluorine ventilation fan associated with laser operations will be removing 255 ft^3 per minute and the REF tunnel is 15700 ft^3 in volume, resulting in 0.975 air changes per hour. Thus, r, the fractional airborne-activity removal rate constant is 1.62×10^{-2} m^{-1}. It is noted that r and λ compete to reduce the airborne activity concentrations in the REF tunnel, and Table 3 shows the decline of airborne activity if the fluorine ventilation is left on for 1 more hour at the end of the 4-hour run with protons. Note the activity concentration units are given in both SI and English units, Bq cm^{-3} and μCi m^{-3}.

Table 3 also shows the % of the Derived Air Concentration (DAC) for each nuclide of concern. At the end of a 4-hour run, the REF tunnel air will be at 10.9 % of the DAC for the mixture of nuclides present in the air, which translates into about 0.27 mrem per hour for a person immersed in and breathing that air. Keeping the fluorine fan on for 1 additional hour after the run effectively removes the entire amount of airborne radioactivity in the tunnel air.

It is noted that a HEPA filter should be placed on the fluorine ventilation system to prevent particulate radioactivity from being released and spewed on the ground outside the short 2-meter stack. It is noted that the ventilation system for the REF building will spread the radioactivity throughout the building, and *should not be used to vent the tunnel*. The release of gaseous radioactivity to the environment from the fluorine-fan stack is shown in Table 4. Along with N, O, Ar and Ne, it is assumed that C, F, Cl ions will form gaseous compounds. This gaseous release will be evaluated under the NESHAPS criteria by BNL's ESHQ Directorate.

References:

(Co04) J. D. Cossairt, Radiation Physics for Personnel and Environmental Protection, Fermilab Report Tm-1834, Revision 7, Fermi National Accelerator Laboratory (April 2004).

(REF88) 200-MeV Radiation Effects Facility, Final Safety Analysis Report, BNL/NPB-87-29R, Neutral Beam Division, DNE, Brookhaven National Laboratory (November 21, 1988).

(Te85) K. Tesch, "A simple estimation of the lateral shielding for proton accelerators in the energy range from 50 to 1000 MeV," Rad. Prot. Dos. 11 (1985) 165-172.

(Ga70) T. A. Gabriel, Calculation of the Long-Lived Induced Activity in Soil Produced by 200 MeV Protons, ORNL-TM-2848 (1970).

(10CFR 835) Appendix A to Part 835-Derived Air Concentrations (DAC) For Controlling Radiation Exposure To Workers At DOE Facilities, United States Department of Energy, 10 CFR Part 835, Occupational Radiation Protection; Final Rule, 59662 Federal Register / Vol. 63, No. 213 / Wednesday, November 4, 1998 / Rules and Regulations.

Table 2 Radionuclides With Half-Life > 1 Minute That Can Be Produced In Air Via Spallation Or Thermal Neutron Capture (Co04)

Nuclide	Halflife, m	Cross Section, mb	Target
^{3}H	6.46E+06	3.00E+01	N
		3.00E+01	O
^{7}Be	7.63E+04	1.00E+01	N
		5.00E+00	O
		6.00E-01	Ar
^{11}C	2.04E+01	1.00E+01	N
		7.00E-01	O
		7.00E-01	Ar
^{14}C	3.01E+09	1.64E+03[a]	N
^{13}N	9.96E+00	1.00E+01	N
		9.00E+00	O
		8.00E-01	Ar
^{14}O	1.20E+00	1.00E+00	O
		6.00E-02	Ar
^{15}O	2.03E+00	4.00E+01	O
^{18}F	1.10E+02	6.00E+00	Ar
^{24}Ne	3.40E+00	1.20E-01	Ar
^{22}Na	1.37E+06	1.00E+01	Ar
^{24}Na	9.00E+02	7.00E+00	Ar
^{27}Mg	9.46E+00	2.50E+00	Ar
^{28}Mg	1.25E+03	4.00E-01	Ar
^{28}Al	2.25E+00	1.30E+01	Ar
^{29}Al	6.60E+00	4.00E+00	Ar
^{31}Si	1.57E+02	6.00E+00	Ar
^{30}P	2.50E+00	4.40E+00	Ar
^{32}P	2.06E+04	2.50E+01	Ar
^{33}P	3.64E+04	9.00E+00	Ar
^{35}S	1.26E+05	2.30E+01	Ar
^{34m}Cl	3.20E+01	7.00E-01	Ar
^{41}Ar	1.08E+02	6.60E+02[a]	Ar

[a]Thermal neutron capture cross section.

Table 3 Radioactivity in the Air in the REF Tunnel

Nuclide	Target	Activity at 4 Hours With Fluorine Fan, Bq	Activity Concentration at 4 Hours With Fluorine Fan, Bq cm^{-3}	Activity Concentration at 4 Hours With Fluorine Fan, $\mu Ci\ m^{-3}$	Inhaled DAC[a] for Radiation Worker, $\mu Ci\ m^{-3}$	% DAC at 4 Hours with Fluorine Fan	% DAC after 4 hour Run With Fluorine Fan Plus 1 Hour of Additional Fluorine Fan
^{3}H	N	4.77E+01	1.12E-07	3.02E-06	20.00	1.51E-05	4.31E-07
	O	1.22E+01	2.86E-08	7.74E-07	20.00	3.87E-06	1.10E-07
^{7}Be	N	1.34E+03	3.15E-06	8.53E-05	9.00	9.47E-04	1.21E-05
	O	1.72E+02	4.04E-07	1.09E-05	9.00	1.21E-04	1.55E-06
	Ar	2.99E-01	7.02E-10	1.90E-08	9.00	2.11E-07	2.70E-09
^{11}C	N	1.66E+06	3.90E-03	1.05E-01	4.00	2.63E+00	1.95E-03
	O	2.98E+04	6.99E-05	1.89E-03	4.00	4.72E-02	3.50E-05
	Ar	4.31E+02	1.01E-06	2.74E-05	4.00	6.84E-04	5.08E-07
^{14}C	N	5.59E+00	1.31E-08	3.54E-07	1.00	3.54E-05	5.05E-08
^{13}N	N	1.99E+06	4.67E-03	1.26E-01	4.00	3.16E+00	2.77E-04
	O	4.59E+05	1.08E-03	2.91E-02	4.00	7.27E-01	6.37E-05
	Ar	5.91E+02	1.39E-06	3.75E-05	4.00	9.37E-04	8.21E-08
^{14}O	O	6.11E+04	1.43E-04	3.88E-03	4.00	9.70E-02	4.94E-19
	Ar	5.32E+01	1.25E-07	3.37E-06	4.00	8.43E-05	4.30E-22
^{15}O	O	2.40E+06	5.63E-03	1.52E-01	4.00	3.81E+00	2.76E-11
^{18}F	Ar	1.52E+03	3.57E-06	9.65E-05	4.00	2.41E-03	9.41E-06
^{24}Ne	Ar	1.01E+02	2.38E-07	6.42E-06	3.00	2.14E-04	4.47E-12
^{22}Na	Ar	2.78E-01	6.52E-10	1.76E-08	0.30	5.88E-06	2.51E-09
^{24}Na	Ar	2.84E+02	6.66E-07	1.80E-05	0.90	2.00E-03	2.45E-06
^{27}Mg	Ar	1.86E+03	4.38E-06	1.18E-04	5.00	2.36E-03	2.08E-07

^{28}Mg	Ar	1.18E+01	2.76E-08	7.47E-07	0.50	1.49E-04	1.03E-07
^{28}Al	Ar	1.12E+04	2.64E-05	7.14E-04	2.00	3.57E-02	9.58E-13
^{29}Al	Ar	3.16E+03	7.41E-06	2.00E-04	3.00	6.67E-03	5.23E-08
^{31}Si	Ar	1.16E+03	2.72E-06	7.36E-05	10.00	7.36E-04	8.04E-06
^{30}P	Ar	3.79E+03	8.89E-06	2.40E-04	3.00	8.01E-03	2.05E-12
^{32}P	Ar	4.61E+01	1.08E-07	2.93E-06	0.20	1.46E-03	4.16E-07
^{33}P	Ar	9.40E+00	2.21E-08	5.96E-07	1.00	5.96E-05	8.48E-08
^{35}S	Ar	6.95E+00	1.63E-08	4.41E-07	0.90	4.90E-05	6.28E-08
^{34m}Cl	Ar	3.64E+02	8.55E-07	2.31E-05	3.00	7.70E-04	8.98E-07
^{41}Ar	Ar	1.69E+05	3.98E-04	1.08E-02	3.00	3.58E-01	1.04E-03
Sum						1.09E+01	3.41E-03

[a] 5000 mrem yr^{-1} and 40 hrs wk^{-1} for 50 weeks; that is, 2.5 mrem per hour (10CFR 835)
[b] Immersion in semi-infinite cloud (10CFR 835)
[c] Assumed equivalent to ^{41}Ar

Table 4 Activity Release Rate Per 4 Hour Run from the 2-Meter Fluorine-Fan Vent Stack

Nuclide	Target	Activity Release Rate up Stack With No Filter, $\mu Ci\ s^{-1}$	Activity Release Rate up Stack With HEPA Filter, $\mu Ci\ s^{-1}$
^{3}H	N	3.56E-07	
	O	9.11E-08	
^{7}Be	N	1.00E-05	
	O	1.28E-06	
	Ar	2.23E-09	
^{11}C	N	1.22E-02	1.22E-02
	O	2.18E-04	2.18E-04
	Ar	3.16E-06	3.16E-06
^{14}C	N	4.17E-08	4.17E-08
^{13}N	N	1.46E-02	1.46E-02
	O	3.35E-03	3.35E-03
	Ar	4.32E-06	4.32E-06
^{14}O	O	4.47E-04	4.47E-04
	Ar	3.89E-07	3.89E-07
^{15}O	O	1.76E-02	1.76E-02
^{18}F	Ar	1.12E-05	1.12E-05
^{24}Ne	Ar	7.41E-07	7.41E-07
^{22}Na	Ar	2.08E-09	
^{24}Na	Ar	2.11E-06	
^{27}Mg	Ar	1.36E-05	
^{28}Mg	Ar	8.77E-08	
^{28}Al	Ar	8.23E-05	
^{29}Al	Ar	2.31E-05	
^{31}Si	Ar	8.54E-06	
^{30}P	Ar	2.77E-05	
^{32}P	Ar	3.44E-07	
^{33}P	Ar	7.02E-08	
^{35}S	Ar	5.19E-08	
^{34m}Cl	Ar	2.67E-06	2.67E-06
^{41}Ar	Ar	1.25E-03	1.25E-03